

Experiments in Materials Science and Engineering

by Tariq A. Khraishi and Marwan S. Al-Haik

Included in this preview:

- Copyright Page
- Table of Contents
- Excerpt of Chapter 1, 2 and 3

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Sneak Preview

EXPERIMENTS IN MATERIALS SCIENCE AND ENGINEERING

Tariq A. Khraishi and Marwan S. Al-Haik



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DEDICATION

I dedicate this book to my wife and children who had to put up with a lot of my days and nights away from them, including many weekends, so that I could generate this book. I also dedicate it to my parents who spent a lot of their resources on getting me through my university studies.

T. Khraishi

To the memory of my two colleagues, Kevin Granata and Liviu Librescu, who sacrificed their own lives protecting the students of Virginia Tech on April 17, 2007. Although I will never get to meet them, they have already taught me a lot and for this I humbly dedicate this book to their memory.

M. Al-Haik

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PREFACE

This is the First Edition of *Experiments in Materials Science and Engineering*. The principal idea behind this textbook arose from the need to consolidate experimental laboratory procedures and materials into a single self-contained and well-explained book. Another reason was to share some uncommon, advanced, and new experiments that today's undergraduate student can be exposed to and benefit from.

The book is divided into 14 chapters, in addition to the preface and dedication parts. The chapters go into sufficient detail on how to perform the different experiments contained within them. This involves a host of illustrations, figures, and equations to better explain the material. Several of those chapters go into common experiments that can be found in a materials science/engineering undergraduate curriculum, or in other engineering curricula. These are things like metallography, macro hardness testing, and tensile testing of materials. This new book, however, discusses experiments not typically seen in undergraduate labs (examples: powder metallurgy, the effect of strain-hardening on material hardness, paper towel tension test, and nano-indentation).

Although many times the experiments or labs call for the availability of certain equipment, machines, and/or apparatuses, several of those are commonly found in materials science and material engineering labs (including mechanical testing and mechanics laboratories) around the nation and around the world. Therefore, it is not difficult to replace your equipment with the ones presented here, since the physical concepts behind such equipment do not change for a given test. Each chapter contains a feature called “*Note to instructors*.” In this feature and within each experiment write-up, several hints and suggestions are provided to replace the exhibited equipment/machines/apparatuses with other suitable replacements.

Lastly, one of the nice characteristics about this book is a feature included in all chapters, called the “*To-Do List*.” This contains a list of points that will guide students to writing technical reports documenting their experiments following each chapter. This is very helpful for instructors, as it saves them the time and effort needed to come up with specific items for students to do following each experiment/lab. It is also helpful for students, as it reminds them of the important points concerning their experiments. To this effect, an entire chapter in this book is dedicated to technical report writing. The chapter on this will set a standard for the students to follow as it teaches them the typical format of a technical report. It is instructional for teachers to spend some time going over this chapter to help the students reach uniformity (not to mention clarity), in their lab report submissions.

We hope this textbook will benefit all those interested in experiments in materials science and materials engineering (including engineering mechanics).

CHAPTER 1

LABORATORY SAFETY

The following are a set of safety rules that are commonly practiced in materials science and engineering labs:

1. Safety glasses/goggles must be worn in all labs when any experiments are running (especially those involving chemical substances and flying/moving objects). Standard or average safety glasses/goggles are adequate for most procedures. However side shields may be necessary for some operations.
2. Rubber gloves should be worn when dealing with any chemical. Also, furnace-rated gloves should be worn when dealing with furnaces.
3. Fume facemasks should be worn when dealing with chemicals.
4. Identify the eye wash areas and lab/building exits closest to you from day one in the lab.
5. Material safety data sheets are available in the lab in case you need to review them.
6. Closed-toe shoes are required at all times in the lab (i.e., no sandals or flip-flops).
7. Long pants or long skirts are required in the lab at all times.
8. No tank tops or tube tops are allowed in the lab. The torso and shoulders must be covered by a shirt, or lab coat. Also very loose sleeves must be rolled above the elbow or restricted so that they cannot become tangled in equipment.
9. Long hair must be tied back while operating machinery.
10. Unsafe behavior including improper use of equipment will not be tolerated.
11. No food or drinks are allowed in the laboratory at any time.
12. The laboratory must be kept clean at all times.
13. Bring your textbook to each lab to reference learning material in case there is a need.

14. Bring yourself to each lab. Attendance is a must by every student and absence will negatively impact your lab grade unless it is excused absence for extenuating circumstance. Moreover, you have to attend on time at the beginning of a lab. Do not come late to labs.
15. Always follow instructions from the lab instructor(s).
16. Failure to abide by these rules will result in loss of laboratory privileges. The instructors may ask anyone to leave at any time for failure to abide by these rules.

Note to instructors: You can augment or edit the above rules in any way that is most suitable for your lab/class situation.

CHAPTER 2

TECHNICAL

REPORT WRITING

GENERAL POINTS

- Assume that the reader has a copy of the lab manual, including figures.
- If you feel it necessary to include part of the manual or its figures, place them in an Appendix (unless their insertion in the text is important for the results).
- Figures in the appendix, however, should not be referenced in the main body of the report. Simply state that more details are given in Appendix A (or B or whatever).

DETAILS

- The report should be detailed to a degree that would allow the reader to rebuild and repeat the experiment, if so desired.
- Reports, in general, are self-contained and require very little outside reading for complete content understanding.

MORE POINTERS

- Be neat and orderly.
- Reports should be typed and checked for spelling and grammatical errors.
- The cover sheet should include:
 - the name of the experiment, the author, date of the experiment
 - other group members, the course title, the class/lab section and group number

ORGANIZATION, ETC

- Clearly separate the different sections, using appropriate headings, numbered in accordance with their appearance in the contents page.
- The report shall have a contents page, with each of the sections numbered and listed by page number.
- The main body of the report begins with the Abstract.
- Put the page number (i.e., 1) at the bottom center, halfway up the bottom margin of the Abstract (first page). The Title page and the Table of Contents page are not numbered.
- The appendices each begin on a new page, numbered with a capital letter, a dash, and an Arabic number (i.e., A-1, B-3, etc.).
- All figures, including graphs, shall be labeled with a Figure # and a caption.
- All figures and tables shall be referenced in the body of the report.
- Do not submit glued, taped, or stapled figures on the final report. If need be, photocopy the entire page. Better yet, make a scanned image of the figure and insert into the text. Acknowledge the source of such data.

LANGUAGE POINTERS

- Always avoid using the first and second person (I, we, you, etc.). The third person is appropriate. For example, instead of “We tested steel in uniaxial tension,” say “Steel was tested in uniaxial tension.”
- Use the past tense at all times unless it’s truly awkward. The present tense is acceptable for facts that are generally true.
- For example, it is appropriate to say that “steel is widely used in structural applications because it is both strong and ductile.” But when discussing your results, you must use past tense: “the steel tested was found to be both strong and ductile.”

REPORT CONTENT

- Abstract
- 1.0 Introduction
- 2.0 Experimental Apparatus and Methods
- 3.0 Results
- 4.0 Discussion
- 5.0 Conclusions
- 6.0 To-Do List
- References
- Appendices

ABSTRACT

- Summarize what was done and what was found in an experiment.
- The abstract should be brief, often only one paragraph, but should highlight all of the relevant information.
- Its heading is centered at the top of the first page

INTRODUCTION

- Any generally accepted equation or fact that is used in the Discussion section to explain your results.
- Summarize the important theoretical assumptions and present the governing equations with some explanation of their origins (a derivation may be appropriate in some cases).
- Theorems which are central to the purpose of the experiment or to the final evaluation of the data.
- Present these theorems in their mathematical forms and define all symbols used.
- All equations should be written on a line of their own with an equation number as is done throughout this manual.
- It is sometimes customary to include a Nomenclature section before the Introduction.

The following is a list of DO NOT INCLUDES in the Introduction:

- Details of the experiment.
- Theory or equation that is not used in the Discussion section.
- The lab manual.
- Paraphrasing of the lab manual is also not acceptable.

EXPERIMENTAL APPARATUS AND METHODS

- Focus on what was actually performed during the experiment.
- Briefly note the important details of the physical set-up of the experiment and the experimental procedure that was followed.
- Describe any particularly important details, such as how and under what conditions the data was collected.
- Especially note any changes or adjustments which were necessary for satisfactory completion of the experiment.
- Generally, the fewer words, the better.
- Do not give the step-by-step details.

RESULTS

- In the form of graphs or tables.
- All graphs and tables should be explained but not discussed.
- Simply state what the graphs and tables are and leave the deductions and relation to theory to the Discussion section.
- All entries must have units. It is best to put the units in the column where the result is identified.
- Tables and graphs must be labeled, numbered, and given a title.

DISCUSSION

- Fully discuss the results in light of the background information and theory discussed in the introduction.
 - Are your results what you expected?
 - Are they consistent with what was discussed the Introduction?
 - Compare the data to all the theory discussed in the Introduction
 - No new theory should be introduced in the Discussion section

- Explain:
 - Any good or bad results
 - Any strengths and weaknesses of the experimental and computational procedures
 - general purpose of the lab and suggestions as to possible applications of the results or further investigations
- Give Sample Calculations for data listed in tables
- These are your individual comments and should reflect any original thoughts or additional results that were obtained
- Do not answer the questions in the lab manuals as part of the Discussion. They should be answered in their own section, after the Conclusions
- Keep in mind that the questions in the lab manual usually do not represent a complete discussion of your data
- Error analyses:
 - Any explanations for the error and suggestions for decreasing the error should be discussed in the Discussion section
 - The detailed calculations of the error analysis need not be discussed in the main body of the report but instead belong in a separate appendix
- If there are very few results or a lot of results it is appropriate to combine the Results and Discussion sections into a section headed Results and Discussion.
- Then you can present your data, state what equation was used to calculate it, and compare it to theory all in one section.

CONCLUSIONS

- A brief summary of the important results and a brief emphasis of the important points of the Discussion.
- No new information or ideas.
- Summarize what you found and what conclusions you drew from it.
- These conclusions should already have been discussed in the Discussion section so only state them here.

REFERENCES

- The literature, to which direct reference was made in the report, shall be placed here.
- Paraphrasing and direct quotes are to be noted by raised numbers or numbers enclosed in brackets in the report. Another common style for referencing includes the use of the first author's (also called the lead author) last name followed by the year of publication of the reference. Such a referencing style can be used instead of the numbering system but they both can't be used together.
- For the numbering system, placement of the literary references shall be in the sequential order of their appearance in the body of the report. For the other system utilizing the last name, references should be listed (i.e., sorted) alphabetically.

Note to instructors: You can augment or edit the above guides or pointers in any way that is most suitable for your lab/class situation. It is also important to determine to the students up front which style of referencing is to be used in their reports.

CHAPTER 3

MEASUREMENTS AND STATISTICS (EXPERIMENT/LAB 1)

Measurements are an important part of engineering. There would be no use in experimenting if there were no way to differentiate the results. Measurements are also important for design and manufacturing. Without accurate measuring instrumentation there is no way to build and reproduce products. In this lab we will discuss several different methods of measuring some specimens of aluminum tubing stock. To measure the stock, rulers, Vernier calipers, dial calipers, and micrometers will be used.

The specimens that are to be measured are shown in the figures below:

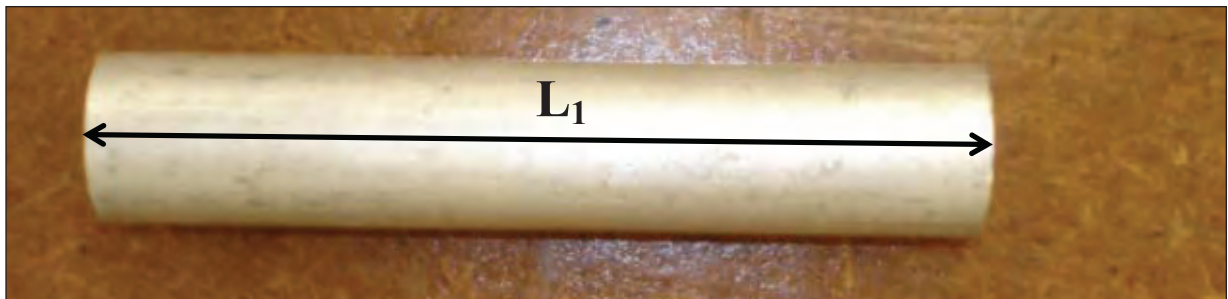


Figure 1. Specimen 1 (tube) Side View

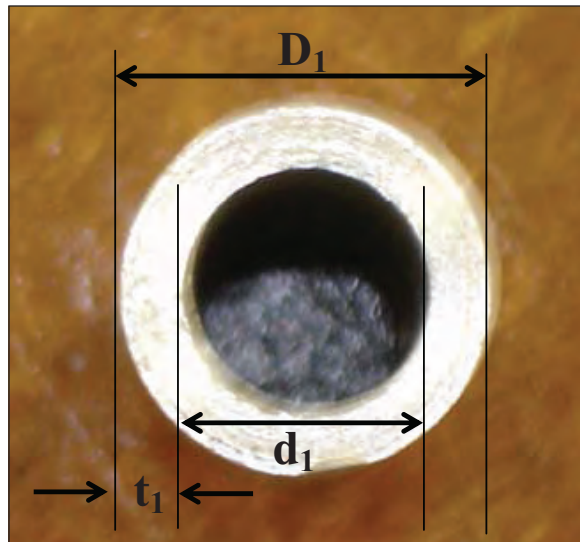


Figure 2. Specimen 1 (tube) Top View

Figure 3. Specimen 2 (tube) Side View



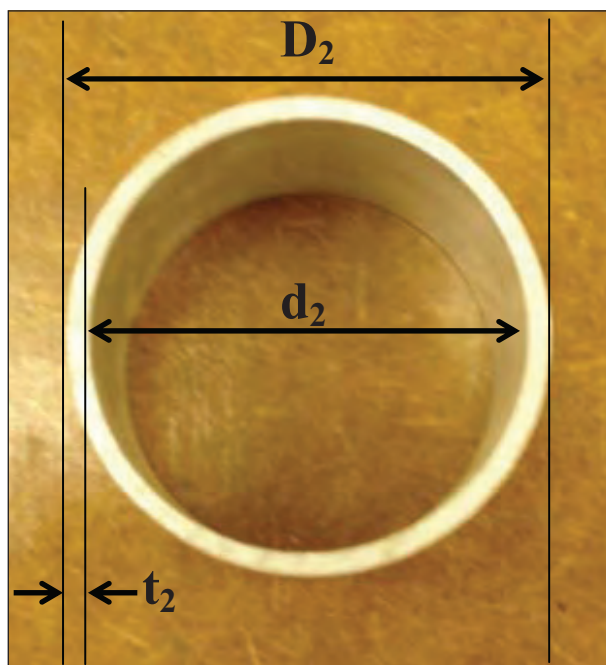


Figure 4. Specimen 2 (tube) Top View

First you should measure and record all dimensions shown on the figures above. These dimensions include length, external diameter, internal diameter, and thickness. Measure these dimensions using a ruler. Once they have been measured using the ruler, then the large dimensions should be measured using Vernier calipers, and the smaller dimensions, such as thickness, should be measured using the micrometer. These values should be recorded in the table below. These values should then be checked using the dial calipers. Once the values are found using each instrument, calculate the volume of material in each specimen. Then calculate the “true percent relative error” using the volume calculated by the ruler measurements as the approximate value and the volume calculated by the micrometer and Vernier calipers as the actual or true value. See the definition of the “true percent relative error” below.

Also measure the mass/weight of each specimen and find from it the density ρ of each specimen. Each student should individually record all of the measurements. Also the “mean” and the “standard deviation” should be calculated (see their definitions below). Once these are calculated check and see if 95% of the measured values fall within mean value $\pm 2S_y$ (S_y being the standard deviation). Then write up a lab report stating the results.

Using a Ruler:

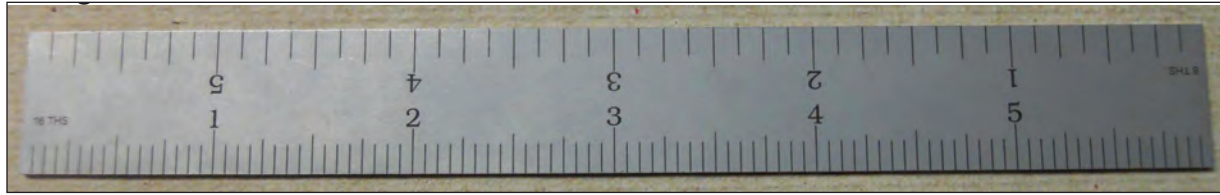


Figure 5. A ruler (in inches)

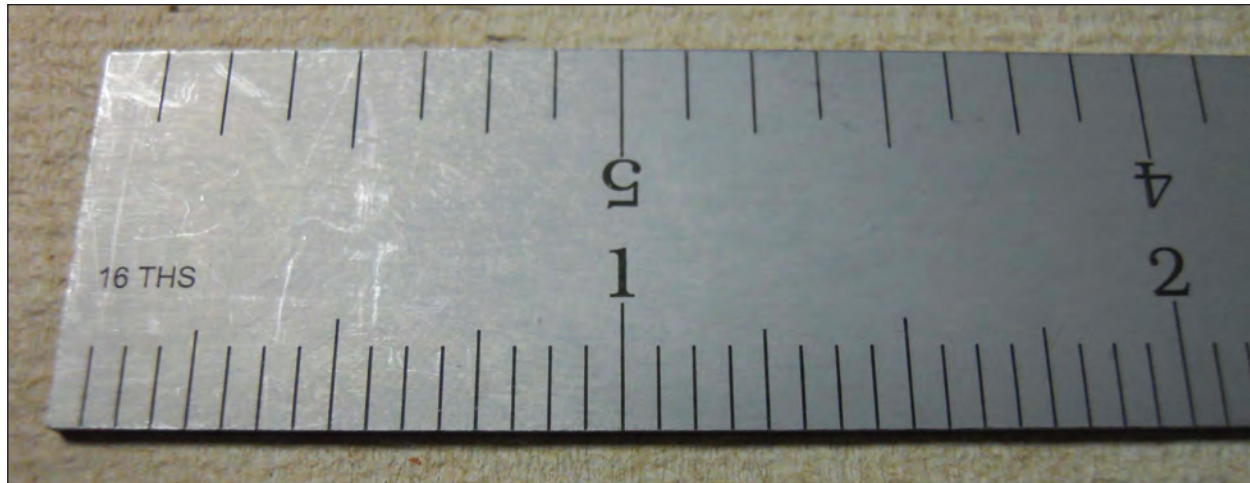


Figure 6. A close-up view of a ruler

- A ruler is an analog device or an analog apparatus (not a digital one), albeit a simple one, that measures the dimensions of an object.
- Figures 5 and 6 show images for a ruler that measures dimensions in inches.
- Each inch, marked on the ruler, is divided into 16 marked divisions on one side of the ruler. On the other side, and for this particular example, each inch is divided into 8 marked divisions. Hence, this particular ruler has two scales on it.
- In this example and using the bottom scale in Figure 6, let's assume that an object's dimension (e.g., length) measures, from the end of the ruler (starting at zero), one whole inch and five and "some" divisions. Let's assume that the "some" here, which represents a fraction of a division, is about half a division (or 0.5 of a division) as seen or estimated by the eye.
- In the above example, the dimension of the object reduces to an addition problem:

$$\begin{aligned} &1 \text{ in} \\ &+ 5 \times 1/16 \text{ in} (= 0.3125 \text{ in}) \\ &+ (1/2) \times (1/16) \text{ in} (= 0.03125 \text{ in}) \\ &1.34375 \text{ in} \end{aligned}$$

- Note in the above numeric example that the first line of addition (i.e., the 1 in) was a certain quantity or known for sure. The same applies to the second line of addition (i.e., to the 0.3125 in). Therefore, there are four digits after the dot (in the 1.3125 in measurement) that are significant digits (i.e., their inclusion is both important and meaningful).
- The third line, however, was an estimate albeit a good estimate (done with our own analog measuring tool: the eye). Including the last line in the addition process produces a fifth digit after the dot in 1.34375 and actually alters the last three digits in the original 1.3125 number.
- In other words, the last four digits (from the right) in the 1.34375 measurement are not certain. From the point of view of writing decimal numbers, one would instead write this measurement as 1.34 inches (instead of 1.34375 in). The second digit in 1.34 after the dot (i.e., the “4”) is also termed a significant digit although its exact quantification is uncertain. Although its exact quantification will depend on who did the eyeballing, most people will estimate the fraction to be 0.5 of one sixteenth of an inch leading to the “4” in the second digit after the dot for the 1.34 dimension measurement here.
- Therefore in this problem there are three significant digits in the 1.34 in measurement and specifically two significant digits after the dot. Trying to figure out what digit comes after the “4” here is extreme speculation and has no significance using this measuring tool. In fact, adding any other digit after the “4” would cause that digit to be called an “insignificant” digit as this would be tantamount to an estimation process over an already estimated process involving the second digit after the dot.
- In conclusion thus, the number of significant digits after the dot are governed by the last digit that can be reasonably estimated.
- Although the above example dealt with inches (which are part of the US Customary Units), it is equally applicable to SI units (e.g., meter/m, centimeter/cm or millimeter/mm).
- Figure 7 shows another quick example illustrating “significant digits.” Assume the shown scale in the figure is in cm. If one wants to determine where the arrow in the figure points to, it can be reasonably estimated that the arrow points to 2.82 or 2.83 (note that each cm is divided into ten divisions with each division represent 0.1 cm). Either of these answers would be appropriate and both of them contain two significant digits after the dot. On the other hand, one cannot say that the arrow points to 2.825, for example. Since the “2” after the dot is uncertain, i.e., has some error associated with it, the “5” after the “2” has even more error or uncertainty associated with it and therefore it is not a significant digit and should not be written in formal technical communications.



Figure 7. Dimension measurement with significant digits

Using a Vernier Caliper:



Figure 8. Vernier caliper

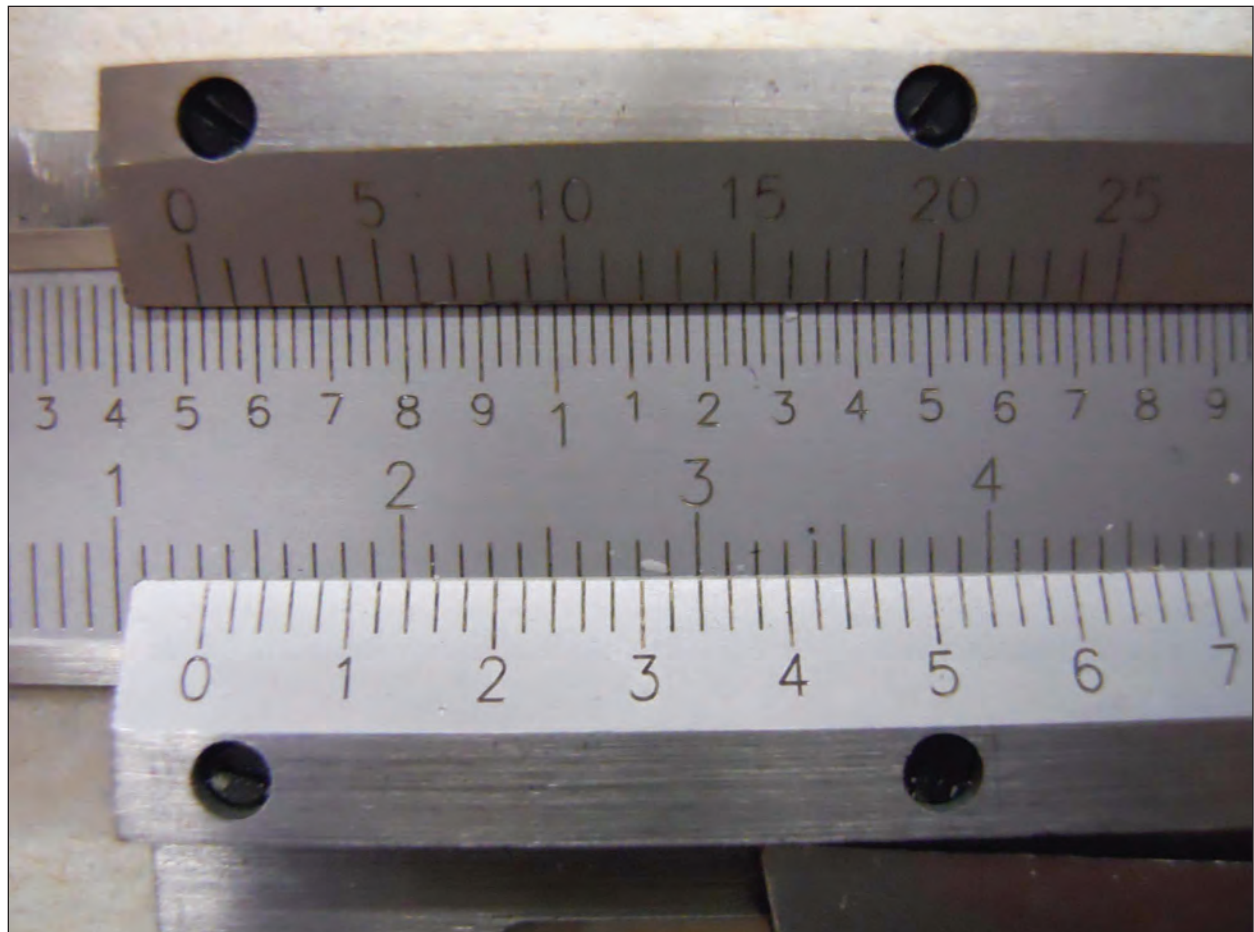


Figure 9. A close-up view of a Vernier caliper

- The Vernier caliper is a tool or an apparatus/device that is used to measure dimensions. It can be used to measure external diameter, internal diameters, lengths, and depths. It comes in analog or digital forms, although the analog version is the most common since it is less costly. Its accuracy is typically 0.02 mm or 0.001 in (i.e., 0.001"). Some Vernier calipers can have an even greater accuracy (e.g., 0.0005"). It is, therefore, considered a precise measuring instrument.
- Close the jaws *lightly* on the object to be measured.
- If you are measuring an object with a round cross-section, make sure that the axis of the object is perpendicular to the caliper jaws. This is necessary to ensure that you are measuring the full diameter and not merely a chord.
- Typical Vernier calipers have two scales engraved or printed on them. One is in inches (US Customary units) and one is in centimeters (metric units).
- There are also a fixed scale and a sliding scale for each of these unit systems.
- To illustrate the use of a Vernier caliper in dimension measurement, consider Figure 9. In this figure, we are going to focus on the bottom scale (metric in cm and fractions of a cm, i.e., mm).
- In Figure 9, the fixed scale is read as a ruler is read. In this case, the opening of the caliper jaws around the object's dimension points to a measurement of 1.3 cm ($1\text{ cm} + 3 \times 0.1\text{cm}$) since there is one whole cm and 3 unmarked divisions (each division representing one tenth of a cm) on the fixed scale. The arrow for the 1.3 cm reading is indicated or pointed out by the 0 on the sliding scale.
- The sliding scale further subdivides the unmarked divisions on the fixed scale. This is where the superiority of the Vernier caliper lies over a ruler. This is a feature that is not present in regular rulers. In regular rulers one would have to estimate a third digit (a second digit after the dot) at this juncture to finish the measurement. With the Vernier caliper, the measurement is still not over for this example.
- In the example caliper shown above, the sliding scale subdivides each 0.1 cm on the fixed scale to ten marked divisions (each worth one tenth of 0.1 cm or 0.01 cm) on the sliding scale. Furthermore, each marked number on the sliding scale is subdivided into five unmarked divisions. In other words, each unmarked division on the sliding scale is worth $(1/5) \times 0.01\text{ cm} = 0.002\text{ cm} = 0.02\text{ mm}$.
- The next step in the measurement is to look at the tick marks on the sliding scale and determine (by the eye) where one of them exactly lines up with a tick mark on the fixed scale.
- In the above example, the third tick after the number 4 on the sliding scale seems to be the one of interest.
- The number 4 on the sliding scale is worth $4 \times 0.01\text{ cm} (= 0.04\text{ cm})$ towards the measurement. The three ticks after the 4 on the sliding scale are worth $3 \times 0.002\text{ cm} (= 0.006\text{ cm})$ to the measurement.
- Hence our measurement reduces down to an addition problem:

$$\begin{array}{r}
 1\text{ cm} \\
 + 0.3\text{ cm} \\
 + 0.04\text{ cm} \\
 + 0.006\text{ cm} \\
 \hline
 1.346\text{ cm}
 \end{array}$$
- Notice that in this problem, and using this particular Vernier caliper, there can only exist three significant digits after the dot. The third or last digit is obtained by reasonable estimation of where a tick on the sliding scale meets a tick on the fixed scale. Since this is an eyeballing technique that involves error, albeit a reasonable technique, no further estimation of digits can be meaningful beyond this digit. Hence, this problem is limited to three significant digits after the dot.

- On those rare occasions when the reading just happens to be a “nice” number like 4 cm, don’t forget to include the zero decimal places showing the precision of the measurement and the reading error. So not 4 cm, but rather 4.000 cm.
- The same method is used for English units.

Using a Micrometer:



Figure 10. A micrometer



Figure 11. A close-up view of a micrometer